TABLE 1

Troubleshooting the Solder-reflow Profile

Problem	Possible Cause
Cracked chip capacitors	Excessive rise rate in preheat zone
Solder balls	Incomplete drying before reflow, excessive drying temperature, improper atmosphere (N_2 vs. air)
Cold solder joints	Insufficient time in reflow zone
Solder unwetted to leads	Excessive drying time, causing fluxes to deteriorate; excessive reflow temperature/time, causing oxidation
Solder not wet on pad	Lead is heating faster than board because of excessive airflow
Parts/board burning	Excessive reflow temperature

gas composition and flow are involved (Figure 2). The system works according to a basic law in physics regarding the deposition of liquids, but is assisted and made repeatable by added mechanical vibrations. A constant "perturbation" of the solder bath is induced by means of a piezoelectric transducer to create a sinusoidal disturbance in the solder stream, producing a 0.004 to 0.012" solder "droplet." The faster the disturbance, the faster the stream will break into droplets. The combination of droplet deflection in the Y-axis and substrate motion in the X-axis produces an accurate pattern of deposits on the substrate. Applications include solder sphere generation for chip scale packages (CSP), cladding for direct-chip-attach (DCA) site preparation, ultra-fine-pitch solder deposition and wafer bumping for flip chips.

- High-quality, low-defect soldering requires identification of the *optimum* temperature profile for reflowing the solder paste and repeating this setting. Solder reflow is accomplished in the reflow zone, where the solder paste is elevated to a temperature greater than its melting point. For Sn63/Pb37 eutectic solder, the liquidus point is 183°C, which must be exceeded by about 20°C to ensure quality reflow. If the product temperature profile is not maintained within the control limits, a defect will occur. Table 1 indicates some of the problems and causes from improper profiling.[4]

  According to *SMT* columnist Dr. Jennie S. Hwang, reflow profiles based on slower heating and cooler temperature will be more in sync with today's complex assemblies and solder paste formulations. Minimizing in-process heat-induced damage will reduce the level of residual stress and problems such as device package cracking ("popcorning"), board warpage and board delamination.[7]
- A strategy in wave soldering called full-process inerting addresses the problem of dross accumulation by virtually eliminating its formation. Depending on the specific technology used, gas consumption may not be much greater than that required to inert the solder waves alone. This is because the technique uses nitrogen that would otherwise be exhausted after treating the waves and directs it through the remainder of the process. A "full-tunnel" inerting machine benefits the entire process via the continuous nitrogen purge. Other benefits include virtual elimination of dross, protection of organic-solder-preservative-treated PCBs via low-oxygen preheating and support of lead-free alternative solder alloys that require effective inerting to counter oxidization.[8]
- Getting the best from the solder-reflow process may just be a matter of challenging the tenets of conventional wisdom. For example, the "ideal" profile is characterized by a 2° to 4°C per second ramp to a dwell zone of 30 to 90 seconds at approximately 150°C. This is followed by a second ramp to about 210°C. Suitable for most applications, the settings are generally ineffective when no-clean pastes are in the picture. Now in use with greater frequency, no-clean pastes require a profile *without* a dwell zone and instead reflect improved response when a straight ramp or "tent" profile is used. For no-clean pastes, which have less active fluxes, excessive dwell times serve only to deplete the flux before reflow. A second advantage of the tent profile is that it speeds the reflow process by reducing occupancy in the oven by the time formerly needed for the dwell zone. Throughput increases average 20 to 25 percent.[9]

  Another "conventional" tenet — avoiding reflow of double-sided PCBs for fear that components will be blown off the bottom — is also challengeable. A formula for second-side mounting can determine a component's candidacy for such placement:

$$C_g/P_a$$

Where C = component's weight in grams and P = total pad area in square inches

ABCs of SMT

Bridging: Errant molten solder that spans two conductors (bridges) to complete an unwanted connection, causing an electrical short.

Capillary action: A force that prompts liquids, such as molten solder, to flow upward between closely spaced solid surfaces, e.g., lead (contact) and pad.

Convection/IR: A solder reflow oven for SMD interconnect that combines convection and infrared (IR) radiation heating.

Dendritic growth: A branching of solder filaments ("whiskers") at interconnect sites because of the presence of moisture or electrical bias, threatening an electrical short.

Dual solder wave: A wavesoldering process in which an initial "wave" of molten solder covers all PCB surfaces contacted. It is followed by a second laminar or "flat" wave that serves to "finish" the board by removing all solder bridges and icicles.

Eutectic: A solder alloy of two or more metals, the lowest melting point of which will initiate its flow.

Hot-air solder-leveling (HASL) : A process in which a solder-coated board is subjected to heated high-velocity air to blow the molten material from plated through-holes and to even-out solder thickness.

Liquidus: The temperature at which a solder becomes molten (vs. solidus).

Rosin flux: The mildest (and least effective) of solder fluxes, generally used in no-clean soldering. A variant, RMA (rosin mildly active), is the most used material for electrical interconnect.

Soak: That part of the solder-reflow process where internal temperature differences between components are permitted to equalize (stabilization).

Solder ball: A defect in which small spheres of solder separate from the main body of material forming the solder joint. Causes include excessive oxides or moisture in the solder paste.

Tombstoning: A soldering defect in which a chip-type part is "pulled" into a vertical or near-vertical position with only one of its terminals connected. It is caused by force imbalances during solder reflow.

(g/in^2 must be less than 30 for second-side mount).

For example, to anchor parts larger than 68-pin PLCCs (e.g., relays, high-mass/low-lead count), most assemblers use an epoxy. In other cases, solders of different melting points can be used. If the bottom is reflowed first using a high-melt solder (less than 183°C), the top can be reflowed using a eutectic solder (melting point = 183°C). With this procedure, the bottomside will not reflow when run a second time.[9]

- By far the greatest single factor in the formation of solder balls (the defect, not the contact) is the type and composition of the soldermask. A mask that is too dark, perhaps with a finish conducive to solder ball formation or a formula not adapted to BGA technology, can spell disaster when coupled with no-clean processing. Early in the 1990s, research on soldermasks and solder balls indicated that a roughened mask, e.g., one brushed before the soldering process, caused fewer defects than an untreated mask. This is because the rough surface made it more difficult for solder balls to adhere to the PCB. Researchers subsequently developed a liquid photo-imageable soldermask (LPISM) with increased surface roughness that eliminated up to 99 percent of solder balls, even in assemblies with fine-pitch and BGA technologies. It can be applied in several ways: screen print, curtain coat, air spray and electrostatic spray.[10] SMT

* Vertrel XMS

** SIPAD; Siemens AG

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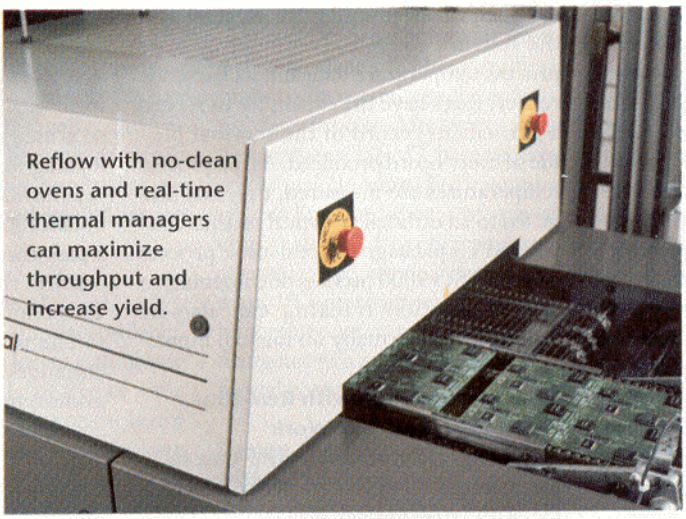
Soldering Application

By Rich Feely and Greg Jones, Ph.D.

In today's market, SMT assemblers and manufacturers must make every effort to maximize reflow throughput and increase yield. Success depends on two critical factors: minimizing oven downtime and the ability to precisely define and monitor the thermal process in real-time. The no-clean oven and the real-time thermal manager are tools designed specifically to help SMT assemblers achieve these goals.



Reflow with no-clean ovens and real-time thermal managers can maximize throughput and increase yield.

Flux Deposit Removal and Oven Downtime

For reflow oven users, one of the major causes of production downtime is oven maintenance. In a high-volume production facility, the reflow oven must be shut down to remove flux deposits every two to six weeks. In a facility running a 24-hour operation, it is common for the oven to be cleaned weekly.

Reflow oven flux buildup is primarily due to three factors: the use of low-solids pastes, nitrogen recirculation and refrigerated board cooling. If flux deposits are not removed from the oven's heater cavity, these waste deposits can drip onto printed circuit boards (PCB) at the most critical point in the reflow process. Flux-clogged convection jets or nozzles can destabilize heat-transfer profiles. Flux can also contaminate conveyor-positioning shafts, making width adjustment difficult and causing board-support problems.

Conventional reflow ovens utilize a variety of methods to remove flux from the oven. These methods include burning off flux residues at extremely high temperatures (upward of 450°C), or condensing flux in a heat exchanger that contains removable fins for cleaning. Lower maintenance designs use condensation plates, or trays, external to the cooling zone to reduce flux buildup. The problem with these cleaning processes is that they inevitably cause oven performance problems that lead to further downtime. Disassembling flux-contaminated nitrogen heater cavities breaks cover seals, and broken seals lead to increased nitrogen consumption. In addition, scraping hardened flux deposits from the heater cavity has the potential to damage convection gas supply nozzles. It is extremely difficult to restore an oven to its original factory condition after the seals and gas nozzles have been damaged.

These practices are so common that manufacturers have come to view frequent flux removal as a cost of doing business. The widespread notion that weekly oven cleaning and maintenance are part of a 24-hour reflow operation prevents many plant managers from realizing just how much production time is lost.

The No-clean Reflow Oven

The optimal solution to the problem of production downtime as a result of frequent oven cleaning is the no-clean

oven. The no-clean oven has been designed to automatically prevent heater cavity flux buildup and eliminate downtime due to flux removal.

The no-clean oven maintains its clean heater chambers by using a cavity design that keeps reflow process gas above flux condensation temperature at all times. The no-clean cavity design produces a cascading gas effect that maintains positive gas pressure in the reflow zone. This prevents flux particles suspended in the reflow gas from solidifying in the oven cavity. Instead of allowing flux to accumulate in the heater cavity, the contaminated gas is purged toward the exhausts. Flux accumulates in disposable ducts within the exhaust system (Figure 1).

The design of the no-clean oven offers minimal maintenance downtime. Once the machine is placed in-line, users have the ability to run boards on a 24-hour basis. The result is higher yields and a greater profitability on the SMT line.

Real-time Thermal Manager

The real-time thermal manager is capable of continuously monitoring process temperature in the reflow oven. There are 30 thermocouples embedded in two slim stainless-steel probes permanently mounted just above or below the conveyor. The probe thermocouples continuously monitor the process temperatures, taking readings as frequently as every five seconds. These temperatures are graphically displayed as "Process Profiles" on the user's computer screen. All data is recorded permanently to the hard drive, giving users the ability to review process data from any previous production date. The real-time thermal manager reveals temperature variations that may be hidden from the oven-control thermocouples, making any temperature drift during production and its location visible on screen.

The real-time thermal manager provides a product profile for every board processed by creating a mathematical correlation between product profile, as measured by a pass-through profiler, and process temperature, as measured by the real-time thermal manager thermocouple probes. This "virtual" product profile is calculated every 30 seconds, and virtual profile statistics, such as peak temperature, are also calculated and continuously updated. The instant the virtual profile falls outside the defined process window, an alarm sounds. This feature can also turn on an alarm light or even shut down the oven-feed conveyor. The real-time thermal manager is an excellent tool for zero-defect production because it eliminates the potential for product defects due to thermal variations.

The real-time thermal manager is also available with an automated prediction tool that allows users to predict how changes to belt speed and oven set-points will affect a product profile. In the automated mode, the thermal manager will create and evaluate thousands of potential product profiles, automatically selecting the profile that best fits the process window. The automated prediction tool is also capable of finding common recipes for lines that run multiple dissimilar products.

When virtual profiling is combined with the system's ability to continuously store process temperature data and its bar-code reader, users have the capability to record a permanent record of the thermal profile of every board produced. As the process temperatures are measured, they can also be fed to an external statistical process control (SPC) package for real-time process control. ISO 9000 process documentation and production tracking can also be achieved with virtually no manual input.

The No-clean Oven with Real-time Thermal Manager at Work

An additional benefit of the real-time thermal manager is that periodic verification profiles with a pass-through profiler do not have to be run. The virtual profile is verifying the process continuously. This continuous process verification complements the reliability and low downtime of the no-clean oven.

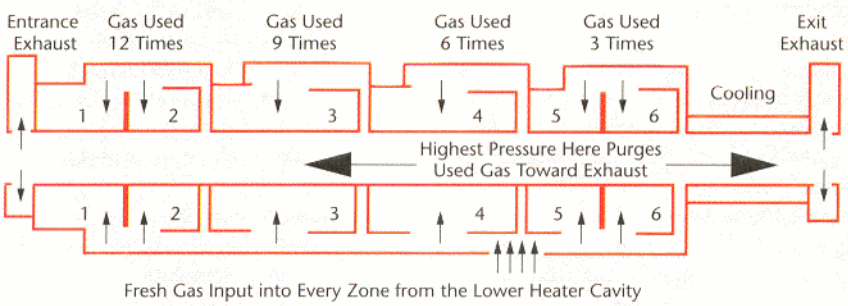


Figure 1. Positive pressure in the reflow zone purges flux from heater cavity.

Few process engineers believe that the no-clean oven is capable of running non-stop for up to a year without preventive maintenance. The real-time thermal monitor confirms that the process is within the acceptable window and that the no-clean oven is running within process parameters, allowing users to get the maximum benefit from the oven's low maintenance requirements and high mean time between failures (MTBF).

For example, the real-time thermal manager has proven valuable to Lucent Technologies, in Columbus, Ohio, in a number of ways:

Preventing defects. Alarms have prevented defects on several occasions. In one situation, a heater was not responding correctly and the temperature in the reflow zone was dropping below the alarm limit. The thermal manager identified this failure and prevented a cold solder problem.

Process setup. This plant runs a large variety of products, from very thin Teflon boards to heavy plated boards that have a regular FR-4 PCB bonded with adhesive to a 0.25" aluminum plate. Oven performance for the whole range of products has been analyzed with the thermal manager to determine how well the heaters perform with a given type of load. This analysis is used to determine the maximum oven loading for a given product.

Eliminated weekly profiling. Prior to obtaining the real-time thermal manager, a pass-through profile was run weekly to confirm that the ovens were within spec. This requirement has been eliminated.

The no-clean oven has also provided enhanced performance. The previous ovens required cleaning every month; the no-clean oven has proven capable of running nine months without cleaning. Lucent is currently using the real-time thermal monitor to determine the necessary intervals for preventive cleaning. The company estimates that the preventive-maintenance interval will be between three to six times longer than the previous interval, depending on the line and the product being run. SMT

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CLEANING

In the era of "no-clean" solder pastes, precision cleaning of assemblies has assumed a new dimension. The question assemblers must ask is determined by whether cleaning is indicated by a PCB's reliability demands; i.e., is the cleaning step required so that the end product will perform in the designated environment for a minimum period or number of cycles?

By Mike Bixenman

During the '90s, printed circuit board (PCB) assembly has taken on new dimensions. Vapor-degreasing solvents are phased out because of environmental regulation. "No-clean" processes constitute a desirable technology shift; when cleaning is contemplated, water-soluble fluxes are generally the choice; finally, cleanliness specifications are not required for bare boards and components, because the completed assemblies are *normally* washed.

The 'End' of Cleaning?

Rosin flux is an excellent "encapsulant," which means that it leaves a nonionic residue when formulated free of ionic activators. Ignoring residue on the board is an attractive option for those looking to eliminate ozone-depleting chemicals. For that reason, considerable time, effort and investment are devoted to no-clean technology. As a result, many technological advances in low-solids flux and machine technology were developed to support this technology shift. The question now becomes, why clean?

Actually, there is a common misconception that the cleaning of assemblies is no longer required. But freedom from harmful contaminants that adversely affect functionality is as important to reliability as the robustness of the solder connections. Cleaning still plays an important role even in the successful implementation of a no-clean process. Incoming parts as well as control of the assembly environment still must meet cleanliness standards if post-solder cleaning is to be eliminated.

High-reliability applications require the benefits of controlled, established post-solder cleaning processes, that use chemistries optimized for the material to be cleaned. Those applications cannot adhere to the requirements of a no-clean process. Moreover, continual developments in SMT have necessitated additional cleaning. For example, the tighter lines and spaces of area-array, chip scale and flip chip packages on assemblies require cleaning under their many I/O interconnects. Cleaning is an important operation for optimum performance of assemblies requiring conformal coatings.

Design the PCB with Cleaning in Mind

When assemblies require post-solder cleaning, there may be tradeoffs to consider when designing for parts layout, soldering and cleaning. With high-density surface mount assemblies, the designer should provide the ability to clean. The following are design options worth considering:

1. Optimum orientation of components
2. Minimal obstructions for spraying under components
3. Use of high-energy jets for wash chemistry
4. Use of fine sprays for rinsing (liquid droplets are smaller than spaces between components and substrate)
5. Elimination of "shadowing," i.e., taller components are placed farthest from spray nozzles; smallest parts are closest
6. Parts placement (see sidebar): Passive chip components (or cylindrical through-hole types) are oriented so that their long axes are perpendicular to the direction of spray. Dual in-line and small-outline integrated circuit (SOIC) components are placed lengthwise along the line of spray. Orientation of components with connections along all sides of a square (e.g., quad flat packs (QFP) or leadless ceramic chip carriers) is such that leading edges are 90° to the direction of spray.

Overall, component placement should be planned so that the "best" evacuation of liquid is accommodated, e.g., in distinct rows with spacing for liquids to drain off the sides of the boards, and with the assurance that cleaning is never impeded when ball grid arrays (BGA) or chip scale packages (CSP) are present. Designers should bear in mind the product's appearance, what it does and how it is to be manufactured. Specifically, how does each step in the assembly process affect all the others? Assemblers who recognize those requirements at the outset of design and integrate them for total optimization hold the key to success.

Pre-assembly Devices

Contaminant residues can be introduced to final assemblies via their initial presence on pre-assembly devices and materials. If not removed from parts and boards before assembly, there is